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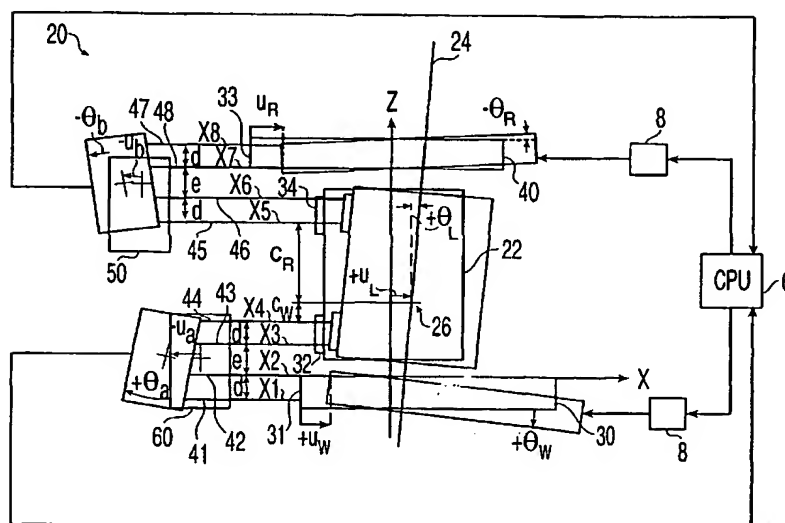
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(54) Title: AN INTERFEROMETER SYSTEM FOR A SEMICONDUCTOR EXPOSURE SYSTEM



(57) Abstract: An interferometer measuring system comprising two moveable members (30, 40) and a reference member (22) that may have significantly less movement, the group having a number of attached measurement mirrors (31, 32, 33, 34), interferometers (41, 42, 43, 44, 45, 46, 47, 48) for measuring position and two optical support blocks (50, 60) for the interferometers. The interferometers (41-48) are used to determine the measured optical path lengths to each of the moveable members (30, 40) and reference member (22) and these positions are used to calculate the misalignment, or error in the relative positions of the moveable members (30, 40) with respect to the reference member (22). This calculated error is then used to correct the misalignment by moving the appropriate members in the manner directed by the calculation.

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AN INTERFEROMETER SYSTEM FOR A SEMICONDUCTOR EXPOSURE SYSTEM

FIELD OF THE INVENTION

5 The present invention relates generally to an interferometer system for position measurement, and more specifically, to an interferometer system and method for improving the accuracy of interferometric measurements.

BACKGROUND OF THE INVENTION

10 Often a semiconductor exposure system used to manufacture semiconductor devices uses a laser interferometer to accurately measure relative displacement between two members. For example, the laser interferometer is used as an apparatus for measuring the coordinates of a wafer stage (i.e. substrate stage) or reticle stage to facilitate highly accurate positioning of a semiconductor wafer or reticle relative to
15 stationary projection optics.

 FIGs. 1 and 2 show a prior art laser interferometer system. The interferometer system typically measures a change in position of measurement mirrors Mx, My attached to movable stage S relative to stationary reference mirror MR attached to projection lens PL. A laser source generates beam B of light, part of which is reflected from reference
20 mirror MR and part of which is reflected from measurement mirror Mx (Fig. 2). The light reflected from mirrors Mx, MR is then combined and reflected into sensor SR. If measurement mirror Mx moves relative to reference mirror MR, the intensity of the combined beam periodically increases and decreases as the reflected light from the two paths alternately interferes constructively and destructively. This constructive and
25 destructive interference is caused by the two beams moving in and out of phase.

 In principle, each half wavelength of movement of the measurement mirror results in a total optical path change of one wavelength and thus, one complete cycle of intensity change. The number of cycle changes indicates the number of wavelengths that the measurement mirror has moved. Therefore, by counting the number of times the
30 intensity of the light cycles between darkest and lightest, the change in position of the measurement mirror can be estimated as an integral number of wavelengths. The simple counting of light cycles, however, does not divulge in what direction the mirrors are moving.

 Actual interferometers are more complicated to be able to determine the direction
35 of movement. This information is determined in a number of ways that may include, for

example, comparing the interference pattern from light of two different wavelengths. And, while data may be processed using a central processing unit, there are also interferometers that output their data optically and therefore do not communicate with a computer in the same manner.

5 Interferometer design also may vary in the placement of certain functional elements. For example, in FIGs. 1 and 2, if the reference mirror MR were positioned a fixed distance from sensor SR (i.e. not on projection lens PL) and only measurement mirror Mx could move relative to sensor SR and reference mirror MR, the interferometer would be a type of "absolute interferometer." An absolute interferometer measures the
10 movement of the measurement mirror. A differential interferometer, however, determines the relative movement between measurement mirror Mx and reference mirror MR where either mirror can move relative to sensor SR. A differential interferometer does not determine which mirror moves, just that one mirror moved in relation to the other. Therefore it does not produce enough information to determine the movement of
15 either mirror relative to a third object without some modification. The interferometer shown in FIGs. 1 and 2 is one such differential interferometer.

As manufacturers of integrated circuits attempt to increase circuit density and reduce circuit feature size in the devices manufactured, interferometers are required to provide more precise measurement data. The precision with which interferometers
20 provide position control has been improved by technical advances in the design of various optical components including lasers and photosensors. But the performance of interferometers is still limited by changes in optical path length due to environmental disturbances, such as thermal expansion, that cause movement of the optical components of the interferometer system. When optical components, such as beam splitter BS, tilt or
25 rotate for any reason whatsoever the distance between reference mirror MR and beam splitter BS changes (Fig. 2). This movement of beam splitter BS causes an error in the position measurement of stage S which results in misalignment of circuit patterns on wafer W relative to one another.

Current interferometer systems fail to account for the rotation of elements within
30 the interferometer system. In particular, see FIG 3., where interferometers directed to reticle stage (not shown) and wafer stage S are mounted on different blocks. For the purposes of this discussion and this patent in general these blocks are considered rigid bodies and the interferometer elements mounted on them are considered rigidly mounted. But these blocks are not rigidly joined to each other and any relative movement of these
35 blocks will cause the interferometer to produce inaccurate data for the position of wafer

W relative to reticle R. Such inaccuracy leads to poor product because the image from reticle R is not in its intended position on wafer W. Current interferometer systems do not and can not compensate for relative rotation of the blocks because they do not contain the means necessary to determine what that movement is.

- 5 Precise positioning of the circuit patterns is desired to prevent an imperfect final product, a potential decrease in process yield, and a corresponding increase in manufacturing costs. There is, therefore, a need for an interferometer system with the improved capability to determine and compensate for undesired rotation of the optical components of the interferometer system.

10

SUMMARY OF THE INVENTION

- The present invention overcomes deficiencies of the prior art by providing an interferometer measuring system that uses the interferometer system itself to compensate for movement of both the optical components and the moveable members (e.g. wafer and
15 reticle stages) within the system. With interferometer systems that measure the stage position and attitude (rotation and tilt) of a projection exposure device, the optical components (interferometer support blocks) of the interferometer system itself tilt or rotate due to body deformation, so reticle and wafer stage position measurement errors occur. The present invention measures the position and attitude of components within
20 the interferometer system using the interferometer system itself, and uses this to compensate for errors that occur, providing an interferometer system that can position the components of the projection exposure device with higher precision than conventional systems.

- The invention next uses the known relative movement between interferometer
25 support blocks and a reference member to adjust the positions of the other moveable members that have been measured by the optical components on both blocks. Finally, after determining the relative movement of both optical components and moveable members, the invention compensates for undesired movement of the moveable members.

- The interferometer measuring system of a preferred embodiment of the present
30 invention generally comprises, for example, in any single plane, two movable members with attached mirrors, one reference member with attached mirror, two optical support blocks, and the light sources, splitters and reference mirrors necessary for eight interferometer axes arrayed appropriately on the optical support blocks. On the first optical block, two interferometer beams are directed toward the first movable member,
35 and two interferometer beams are directed toward the reference member. Similarly, on

the second optical block, two interferometer beams are directed towards the second moveable member, and two interferometer beams are directed toward the reference member. In this preferred embodiment the movable members are a reticle stage and a wafer stage and the reference member is the projection lens. It should be noted that, since the positions of the moveable members are determined relative to the reference member, the reference member could also move and the invention would still compensate for undesired movement of the moveable members relative thereto.

A method employing the present invention finds the positions of a plurality of movable members relative to each other and accounts and compensates for undesired movement of the movable members and interferometer system components. This method generally comprises first sensing the change in position of two points on each of a plurality of the movable members; calculating the relative change in position of a plurality of the movable members based on the sensed positions; and compensating for undesired movement.

Where the interferometer system includes interferometers mounted on multiple blocks, relative movement between two blocks is determined by having additional steps where the interferometers from each block sense the position of a reference moveable member; then re-define the other moveable members' positions in terms showing their position relative to the reference moveable member. The method can include a step in which a controller then compensates for undesired movement.

The above is a brief description of some deficiencies in the prior art and advantages of the present invention. Other features, advantages, and embodiments of the invention will be apparent to those skilled in the art from the following description, drawings, and claims.

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BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a plan view of a prior art interferometer system for measuring position of a stage movable in x and y directions;

FIG. 2 is a side view of the prior art interferometer system of FIG. 1 showing rotation of optical components of the system;

FIG. 3 is a perspective of a portion of prior art interferometer system of FIGs. 1 and 2 applied to a wafer stage of a projection type exposure apparatus;

FIG. 4 is a side view of the XZ plane component of an interferometer system of the present invention; and

35

FIG. 5 is a side view showing the relative interferometer placement in a preferred embodiment of the present invention.

Corresponding reference characters indicate corresponding parts throughout the several views of the drawings.

DESCRIPTION OF THE INVENTION

5

An interferometer system according to the present invention determines relative displacement and rotation of the optical elements and repositions the movable elements, or provides direction for their repositioning, accounting for the aforementioned movements of the optical elements. Thus, the invention provides the potential to control more precisely the positions of the wafer and reticle in an exposure device. This greater
10 precision permits improved accuracy in circuit patterns on the wafer.

Interferometer systems of the prior art are known to determine reticle and wafer stage displacement and rotation relative to the projection lens using interferometers as described in the background section. The prior art, however, does not determine whether
15 the optical components of the interferometer system have themselves moved. The present invention, on the other hand, coordinates these determinations to create a system whereby wafer stage and reticle positions are both known with respect to projection lens while accounting for displacement and rotation of the interferometer optical components.

To account for movements in the optical components of the interferometer
20 system, the preferred embodiment of the present invention utilizes in each reference plane an eight beam interferometer system in conjunction with the normally existing central processing unit 6 and stage controllers 8 as illustrated in FIG. 4. The interferometers measure optical path length change for the beams directed at the movable members (projection lens assembly 22, wafer stage 30 and reticle stage 40) from the
25 optical components (interferometer blocks 50, 60) in a single plane, for example, the XZ plane. Interferometer mirrors 31, 32, 33 and 34 are mounted on reticle stage 40, wafer stage 30 and projection lens assembly 22 as known in the art. The measured optical path length change data is processed by CPU 6 to determine both wafer stage and reticle displacement and rotation with respect to the projection lens assembly should either stage
30 and/or the blocks upon which the interferometers are mounted change position. Controllers 8 adjust the position of the system components in response to correction information generated by CPU 6.

Another eight beam interferometer system (in addition to the existing central processing unit and stage controllers) may be employed to perform the similar function in
35 the YZ plane and/or XY plane if desired. While the movement of the system components

is in three dimensions, the description herein is limited to a single plane, i.e. as a two dimensional phenomena, in order to clarify the operation of the invention. Persons of ordinary skill in the art will appreciate that the description set forth herein may be equally applied to two or more planes for three dimensional measurement of motion in up to six degrees of freedom. Similarly, the present invention may also be practiced using a four beam interferometer system mounted on one interferometer block to align two moveable members.

Referring again to FIG. 4, interferometer system 20 of the present invention is illustrated in side view in the XZ plane, with the Z axis as shown representing the vertical direction. In order to clarify the schematic representation of the invention as shown in FIG. 4, the reference beams and reference mirrors for each interferometer are not shown. Thus, in a preferred embodiment, eight absolute interferometers provide eight measurement beams, 41-48 as shown. Persons of ordinary skill in the art will appreciate that differential interferometers may be substituted in appropriate locations without departing from the scope of the invention.

In particular, beams are preferably positioned in equidistant pairs such that beam pairs 41-42, 43-44, 45-46 and 47-48 are spaced apart by a common distance (d). Moreover, adjacent beam pair 42-43 and 46-47 are preferably spaced apart at distance (e). But distances (d) and (e) could be unique for each pair without compromising the present invention. Distances (d) and (e) are preferably the same for all pairs as this simplifies the positioning determination. However, the separate pairs may be differently spaced so long as each unique spacing is known and compensated for. Additionally, distances (d) and (e) may also represent only the component of the interferometer beam spacing that is in the plane of interest. For example, since the plane of interest in FIG. 4 is the XZ plane, and also with reference to FIG. 5, interferometer 41 may be offset from interferometer 42 in the Y direction without affecting the value of (d). As will be apparent to one of ordinary skill in the art, no two interferometers may originate or terminate at the same point without resulting in a loss of the data points necessary for the invention to function as described.

The beams are also positioned with respect to a defined reference point 26 on projection lens assembly 22. Preferably reference point 26 corresponds to the vertical center of the main lens within the projection lens assembly such that the vertical distance (Z axis) of beam 44 from reference point 26 is C_w and the corresponding distance from beam 45 to reference point 26 is C_R . Measurement beams 41-48 correspond positionally

to optical path length changes X_{1-8} , calculated according to the invention as described in greater detail below.

In an initial state, specifically when the projection lens assembly 22 and the interferometer system 20 are not tilted, the Z axis matches optical axis 24 of lens assembly 22. According to the methodology of the present invention, projection lens assembly 22 (PL), reticle stage 40 (RS), wafer stage 30 (WS), reticle stage interferometer block 50 (RIB), and wafer stage interferometer block 60 (WIB) are treated as rigid bodies. Thus, the angle of each rigid body relative to the initial optical axis (i.e. the Z axis, perpendicular to the ground) is defined as follows:

- 10 θ_w rotation about the Y axis of wafer stage 30
- θ_L rotation about the Y axis of projection lens 22
- θ_R rotation about the Y axis of reticle stage 40
- θ_a rotation about the Y axis of optical block 60
- 15 θ_b rotation about the Y axis of optical block 50

The movement distance of each rigid body from the initial position is similarly defined as follows:

- u_w x displacement of wafer stage 30
- 20 u_L x displacement of projection lens 22
- u_R x displacement of reticle stage 40
- u_a x displacement of optical block 60
- u_b x displacement of optical block 50

25 Thus, the optical path length change X_{1-8} measured by interferometer beams 41-48, when any or all of the five rigid bodies 22, 30, 40, 50, 60 has translated and/or rotated, may be expressed in relation to the initial state as follows:

- $X_1 = [\text{WS 30 position and tilt}] + [\text{WIB 60 position and tilt}] = [u_w - d\theta_w] - [u_a - (d+e/2)\theta_a]$ (1)
- 30 $X_2 = [\text{WS 30 position and tilt}] + [\text{WIB 60 position and tilt}] = [u_w] - [u_a - (e/2)\theta_a]$ (2)
- $X_3 = [\text{PL 22 position and tilt}] + [\text{WIB 60 position and tilt}] = [u_L - (d+c_w)\theta_L] - [u_a + (e/2)\theta_a]$ (3)
- $X_4 = [\text{PL 22 position and tilt}] + [\text{WIB 60 position and tilt}] = [u_L - c_w\theta_L] - [u_a + (d+e/2)\theta_a]$ (4)
- $X_5 = [\text{PL 22 position and tilt}] + [\text{RIB 50 position and tilt}] = [u_L + c_R\theta_L] - [u_b - (d+e/2)\theta_b]$ (5)
- $X_6 = [\text{PL 22 position and tilt}] + [\text{RIB 50 position and tilt}] = [u_L + (d+c_R)\theta_L] - [u_b - (e/2)\theta_b]$ (6)
- 35 $X_7 = [\text{RS 40 position and tilt}] + [\text{RIB 50 position and tilt}] = [u_R] - [u_b + (e/2)\theta_b]$ (7)

$$X_8 = [\text{RS 40 position and tilt}] + [\text{RIB 50 position and tilt}] = [u_R + d\theta_R] - [u_b + (d+e/2)\theta_b] \quad (8)$$

With these relationships defined, changes in position of the optical elements can be determined. This is accomplished by first calculating the differences between adjacent interferometer beam pairs 41-42, 43-44, 45-46 and 47-48 then dividing by the separation (d) between the beams:

$$(X_2 - X_1)/d = \theta_w - \theta_a \quad (9)$$

$$(X_4 - X_3)/d = \theta_L - \theta_a \quad (10)$$

$$(X_6 - X_5)/d = \theta_L - \theta_b \quad (11)$$

$$(X_8 - X_7)/d = \theta_R - \theta_b \quad (12)$$

Equations (10) and (11) can now be substituted into the equations describing the differences between stage mirrors 31, 33 and mirrors 32, 34 on projection lens assembly 22. The resulting relationships show the differences as functions of moving member displacement and rotation:

$$\begin{aligned} X_2 - X_3 &= [u_w] - [u_a - (e/2)\theta_a] - [u_L - (d+c_w)\theta_L] + [u_a + (e/2)\theta_a] \\ &= u_w + e\theta_a - u_L + (d+c_w)\theta_L \end{aligned}$$

$$\begin{aligned} (10) \rightarrow &= u_w + e(\theta_L - (X_4 - X_3)/d) - u_L + (d+c_w)\theta_L \\ &= u_w - (e/d)(X_4 - X_3) - u_L + (d+c_w+e)\theta_L \end{aligned} \quad (13)$$

$$\begin{aligned} X_7 - X_6 &= [u_R] - [u_b + (e/2)\theta_b] - [u_L + (d+c_R)\theta_L] + [u_b - (e/2)\theta_b] \\ &= u_R - e\theta_b - u_L - (d+c_R)\theta_L \end{aligned}$$

$$\begin{aligned} (11) \rightarrow &= u_R - e(\theta_L - (X_6 - X_5)/d) - u_L - (d+c_R)\theta_L \\ &= u_R + (e/d)(X_6 - X_5) - u_L - (d+c_R+e)\theta_L \end{aligned} \quad (14)$$

These equations are then solved to express the element positions as functions of the measured optical path length changes.

$$(13) \rightarrow u_w - [u_L - (d+c_w+e)\theta_L] = X_2 - X_3 + (e/d)(X_4 - X_3) \quad (15)$$

$$(14) \rightarrow u_R - [u_L + (d+c_R+e)\theta_L] = X_7 - X_6 - (e/d)(X_6 - X_5) \quad (16)$$

$$(9)-(10) \rightarrow \theta_w - \theta_L = (X_2 - X_1)/d - (X_4 - X_3)/d \quad (17)$$

$$(12)-(11) \rightarrow \theta_R - \theta_L = (X_8 - X_7)/d - (X_6 - X_5)/d \quad (18)$$

The left sides of equations (15) through (18) are intermediate steps that begin to show the transition from the position and angle values (u, θ) of the coordinate system created by the initial optical axis Z to the coordinate system created by the optical axis 24 of projection lens assembly 22 after movement or rotation of system elements. For example, $(d+c_w+e)$ of equation (15) is the distance from projection lens 26 to the wafer surface, so $u_w - [u_L - (d+c_w+e)\theta_L]$ shows the transition from the coordinate system created by the initial optical axis to the coordinate system created by the projection lens optical axis 24 after elements of the system have been moved and rotated. Similarly, $\theta_w - \theta_L$ of equation (17) shows the transition from angle θ_w measured from the initial optical axis Z to the relative angle between wafer stage 30 and projection lens assembly 22 after movement or rotation of system elements.

After solution these positions are still described with respect to the Z axis. But with respect to a coordinate system defined around reference point 26 (i.e. optical axis 24 of lens 26) some terms drop out ($u_L = \theta_L = 0$). Therefore, using reference point 26 as a reference moveable member allows a projection system employing the present invention to position both wafer stage and reticle stage relative to the projection lens assembly (specifically reference point 26) according to the following:

$$U_w = X_2 - X_3 + (e/d)(X_4 - X_3) \quad = \text{wafer stage position} \quad (19)$$

$$U_R = X_7 - X_6 - (e/d)(X_6 - X_5) \quad = \text{reticle stage position} \quad (20)$$

$$\Theta_w = (X_2 - X_1)/d - (X_4 - X_3)/d \quad = \text{wafer stage angle} \quad (21)$$

$$\Theta_R = (X_8 - X_7)/d - (X_6 - X_5)/d \quad = \text{reticle stage angle} \quad (22)$$

Thus, if the optical axis of projection lens assembly 22 as described above is made the reference standard, then with the eight beam interferometer system of a preferred embodiment, even if projection lens assembly 22, wafer stage 30, reticle stage 40, reticle stage interferometer block 50, and wafer stage interferometer block 60 are moved and tilted, it is possible to measure and correct for the relative movement and tilt when positioning wafer stage 30 and reticle stage 40.

As depicted, equations (19) - (22) may be viewed as having two components. The first component, a "nominal" component, determines the basic translation of the stage relative to the projection lens assembly 22. The second component, a "correction," accounts for the rotation and movement that cause the various components of the system to deviate in position from the "nominal" position. For example, in equation (19) the nominal component is " $X_2 - X_3$ " and the correction is " $+ (e/d)(X_4 - X_3)$." Similarly, in

equation (21) the nominal component is " $(X_2 - X_1)/d$ " and the correction is " $-(X_4 - X_3)/d$." These nominal and correction components are representations designed to simplify the discussion of the invention. Depending on the specific hardware and software implementation, the present invention does not necessarily differentiate between
5 "nominal" and "correction" during either data acquisition or computation.

It will be observed from the above description that the interferometer system of the present invention provides a number of advantages over prior art systems. Importantly, the interferometer system accounts for displacement of the optical components of the interferometer system due to environmental effects such as thermal
10 fluctuations or vibrations (or translations, since vibration can be considered translation with a time component), thus providing more accurate stage position measurement than possible with prior art interferometer systems.

A further alternative embodiment of the present invention addresses rotation about the Z-axis with the addition of four interferometer reference beams 72, 74, 76, 78 as shown in FIG. 5. (FIG. 5 schematically depicts the relative position of mirrors 31-34
15 in the YZ plane. The interferometer beams which lie in the XZ plane therefore appear in cross-section in FIG. 5.) Each of beams 72-78 is directed to one of mirrors 31, 32, 33, 34, at a point displaced in the Y direction from the other beams already incident on each mirror. Beams 72, 74, 76, 78 are each paired with one other interferometer beam directed
20 to each mirror. For example the difference between the displacement from axes 72, 74, 76, 78 and its partner used as previously described to account for rotation about the Z axis of both moveable members and optical components. For example, interferometer 70 can be paired with either interferometer 52 or 54 as long as it is offset in the Y direction.

The interferometer system of the present invention may be used as a position
25 measurement system of a stage apparatus such as a wafer stage or a mask stage in a one-shot or scan type exposure apparatus for which highly precise driving control is required. But the invention is not limited to use with an exposure apparatus. For example, it may be used to accurately measure the relative displacement between two members in various high precision tools.

As various changes could be made in the above constructions and methods
30 without departing from the scope of the invention, it is intended that all matter contained in the above description and shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense. In particular, although the invention is described using interferometers to supply the necessary data, any sufficiently precise method of
35 acquiring such data would suffice.

We claim:

1. A method employing an interferometer system to determine the relative position, within a given plane, of a plurality of movable members, wherein said interferometer
5 system comprises at least one component supporting a plurality of interferometer measurement beams directed toward at least two moveable members, the method comprising:
 - measuring optical path length change between the at least one interferometer component and said at least two moveable members along each of said plurality of
10 interferometer beams as a result of relative movement of said at least one interferometer component and said members; and
 - determining the relative positions of said moveable members based on said measured optical path length changes.
- 15 2. The method of claim 1 wherein said determining step determines the relative rotational positions of said moveable members.
3. The method according to claim 2, said method further comprising positioning said moveable members with respect to each other based on said determined relative
20 positions.
4. The method according to claim 2, wherein:
 - said measuring comprises projecting at least four interferometer beams, at least two said beams directed at each moveable member; and
 - 25 said determining comprises calculating the relative positions based on optical path length changes as measured by each of said at least four interferometer beams.
5. The method according to claim 4, wherein said interferometer system positions two stages with a lens assembly disposed therebetween in a lithography system, and
30 wherein:
 - a) said measuring comprises projecting at least eight interferometer beams, at least two said beams directed at the lens assembly from each said supporting component and at least two said beams directed at each said moveable member; and
 - b) said determining comprises calculating the relative positions based on optical
35 path length changes as measured by each of said at least eight interferometer beams.

6. The method of claim 5, wherein said determining comprises:
calculating a nominal relative position based on a first selected set of measured
optical path length changes; and
calculating a correction to account for movement of the at least one interferometer
5 system component based on a second selected set of measured optical path length
changes.
7. The method of claim 6, wherein said moveable members comprise a reference
moveable member and a positionable moveable member, and said interferometer
10 measurement beams comprise two adjacent pairs of beams, the beams in each pair spaced
apart by a determined spacing distance and both directed at one moveable member,
wherein adjacent beams of the adjacent pair are spaced apart by a determined adjacent
distance.
- 15 8. The method of claim 7, wherein said reference moveable member is a projection
lens assembly of a lithography exposure system and said positionable moveable
member is a stage of the exposure system.
9. The method of claim 7, wherein said calculating a nominal relative position
20 comprises calculating the difference in optical path length change between the adjacent
beams of the two adjacent pairs of beams.
10. The method of claim 9, wherein said calculating a correction comprises
calculating the difference between the beams directed at the reference member and
25 multiplying said difference by the ratio of said determined adjacent distance over said
determined spacing distance.
11. The method of claim 10, wherein said determining relative positions comprises
adding the calculated nominal position to the correction to determine relative position of
30 the positionable member with respect to the reference member along an axis parallel to
said interferometer beams.
12. The method of claim 7, wherein said calculating a nominal relative position
comprises calculating the difference between the two beams on the positional member
35 and dividing by said determined spacing distance.

13. The method of claim 12, wherein said calculating a correction comprises calculating the difference between the two beams on the reference member and dividing by said determined spacing distance.
- 5 14. The method of claim 13, wherein said determining relative positions comprises subtracting the nominal relative position from the correction to determine relative angular position of the positionable member with respect to the reference member in a plane defined by said interferometer beams.
- 10 15. A method employing an interferometer system to determine the relative positions, within a given plane, of a plurality of movable members, wherein said interferometer system comprises at least one component supporting a plurality of interferometer measurement beams directed toward at least two moveable members, the method comprising:
- 15 measuring optical path length change between the at least one interferometer component and said at least two moveable members along each of the plurality of interferometer beams;
- calculating a nominal relative position based on a first selected set of measured optical path length changes;
- 20 calculating a correction to account for movement of the at least one interferometer system component based on a second selected set of measured optical path length changes; and
- determining relative positions between the moveable members based on the nominal relative positions and said correction.
- 25 16. The method of claim 15 wherein said determining step determines the relative rotational positions of said moveable members.
17. The method of claim 16, said method further comprising positioning said
- 30 members based on said determined relative positions.
18. A method employing an interferometer system to determine the relative position of two movable members within a given plane, wherein said interferometer system comprises an interferometer component supporting a plurality of interferometer
- 35 measurement beams directed towards said moveable members, the method comprising:

projecting two pairs of interferometer measurement beams, one said pair toward each said moveable member;

measuring optical path length change along each said beam, said change resulting from movement of said moveable member relative to said interferometer component;

5 calculating a nominal relative position based on a first set of measured optical path length changes, said first set determining the difference of the change between said pairs,

calculating a correction to account for undesired movement of the moveable members based on a second set of measured optical path length changes, said second set
10 determining the difference of the change within each said pair; and

determining the relative positions of said moveable members based on said nominal relative position and said correction.

19. The method of claim 18 wherein said determining step determines the relative
15 rotational positions of said moveable members.

20. The method of claim 19, said method further comprising calculating a correction to account for undesired rotational movement of said moveable members based on differences between said optical path length changes within each of said pairs.

20 21. A method employing an interferometer system to determine the relative positions of a plurality of movable members with respect to a moveable reference member within a given plane, wherein said interferometer system includes at least two interferometer blocks, each block supporting a plurality of interferometer measurement beams directed
25 at least at the reference moveable member and one other moveable member, the method comprising:

sensing, with interferometers of a first interferometer block, the measured optical path lengths to at least two points on each of a first plurality of moveable members, said first plurality of moveable members including a first moveable member and a reference
30 member;

sensing, with interferometers of a second interferometer block, the measured optical path lengths to at least two points on each of a second plurality of moveable members, said second plurality of moveable members including a second moveable member and said reference member;

35

calculating the positions of said first and second moveable members relative to the reference member based on (i) the measured optical path lengths between the first moveable member and the first interferometer block, (ii) the measured optical path lengths between the second moveable member and the second interferometer block and
5 (iii) the measured optical path lengths between said first and second interferometer blocks and said reference member.

22. The method of claim 21 wherein said calculating step calculates the the relative rotational positions of said moveable members.

10 23. The method of claim 21, further comprising aligning said moveable members based on said calculated positions.

24. A method for controlling stage position relative to a projection lens assembly in a
15 lithography exposure system, comprising:

positioning a stage with respect to a projection lens assembly;
providing an interferometer system comprising at least one interferometer component supporting a plurality of interferometer measurement beams directed at said projection lens assembly and stage, wherein said interferometer measurement beams are
20 disposed in two adjacent pairs, one pair directed at each of the projection lens assembly and stage, the beams in each pair being spaced apart by a determined spacing distance and wherein adjacent beams of the adjacent pair are spaced apart by a determined adjacent distance;

measuring optical path length change between the at least one interferometer
25 component and the projection lens assembly and stage along each of the plurality of interferometer beams;

calculating a nominal relative position of the stage with respect to the projection lens assembly based on a first selected set of measured optical path length changes;

calculating a correction to account for movement of the at least one interferometer
30 system component based on a second selected set of measured optical path length changes;

determining relative positions between the moveable members based on the nominal relative positions and said correction;

controlling the position of the stage with respect to the projection lens assembly in
35 accordance with said determined relative positions.

25. The method of claim 24 wherein said determining step determines the relative rotational positions of said moveable members.
- 5 26. The method of claim 24, wherein said calculating a nominal relative position comprises calculating the optical path length change between the adjacent beams of the two adjacent pairs of beams.
- 10 27. The method of claim 26, wherein said calculating a correction comprises calculating the difference between the beams directed at the reference member and multiplying said difference by the ratio of said adjacent distance over said spacing distance.
- 15 28. The method of claim 27, wherein said determining relative positions comprises adding the calculated nominal position to the correction to determine relative position of the positionable member with respect to the reference member along an axis parallel to said interferometer beams.
- 20 29. The method of claim 24, wherein said calculating a nominal relative position comprises calculating the difference between the two beams on the positional member and dividing by the spacing distance.
- 25 30. The method of claim 29, wherein said calculating a correction comprises calculating the difference between the two beams on the reference member and dividing by the spacing distance.
- 30 31. The method of claim 30, wherein said determining relative positions comprises subtracting the correction relative position and from the nominal to determine relative angular position of the positionable member with respect to the reference member in a plane defined by said interferometer beams.
32. A system for relative positioning of moveable members in a reference plane, comprising:
a first moveable member having a first measurement mirror attached thereto;
- 35

a second moveable member having a second measurement mirror attached thereto;

a third moveable member having at least a third measurement mirror attached thereto;

5 a plurality of interferometers including a plurality of reference mirrors and providing a plurality of measurement beams and a plurality of reference beams to measure optical path length changes;

10 a first optical support block supporting a plurality of said interferometers wherein at least two of said interferometer measurement beams are directed to points on said first measurement mirror and at least two interferometer measurement beams are directed to points on said third measurement mirror and wherein each of said measurement beams is paired with one of said reference beams to provide a signal representing the path length to said measurement mirror;

15 a second optical support block supporting a plurality of said interferometers wherein at least two of said interferometer measurement beams are directed to points on said second measurement mirror and at least two interferometer measurement beams are directed to points on said third measurement mirror and wherein each of said measurement beams is paired with one of said reference beams to provide a signal representing the path length to said measurement mirror;

20 a plurality of sensors for receiving each of said signals; and

at least one controller cooperating with at least each of the first and second moveable members to position at least one of said members with respect to the third moveable member in response to the sensed signals.

25 33. The system for positioning moveable members of claim 32 wherein said at least one controller rotationally positions at least one of said members with respect to the third moveable member in response to the sensed signals.

30 34. The system of claim 32, wherein said third measurement mirror comprises at least two separate mirrors spaced apart in the reference plane.

35 35. The system of claim 32, further comprising:

a computer program product for use in conjunction with a computer system, the computer program product comprising a computer readable storage medium and a

computer program mechanism embedded therein, the computer program mechanism further comprising;

means for receiving data from said interference patterns; and

5 means for calculating a first position of said first moveable member and a second position of said second moveable member, both with respect to said third moveable member wherein both first and second said positions account for movements of a plurality of interferometer elements and moveable members based on said interference patterns.

10 36. The system of claim 32, wherein:

said first moveable member comprises a reticle stage, said second moveable member comprises a wafer stage, and said third moveable member comprises a projection lens assembly including a projection lens; and

15 the interferometer measurement beams from each optical support block are disposed in two adjacent pairs, one pair directed at each of the projection lens assembly and one said stage, the beams in each pair being spaced apart by a spacing distance, and wherein adjacent beams of the adjacent pair are spaced apart by an adjacent distance.

37. The system of claim 36 wherein the wafer stage is positioned relative to the projection lens assembly according to the following relationship:

$$U_w = X_2 - X_3 + (e/d)(X_4 - X_3)$$

wherein,

U_w corresponds to displacement of the wafer stage relative to the projection lens assembly along an axis parallel to the measurement beams,

25 X_2 corresponds to the optical path length change measured by the beam directed at the wafer stage which is the adjacent distance from the beam directed at the projection lens assembly,

X_3 corresponds to the optical path length change measured by the beam directed at the projection lens assembly which is the adjacent distance from the beam directed at the wafer stage, and

30 X_4 corresponds to the optical path length change measured by the beam directed at the projection lens assembly that is the spacing distance from the beam corresponding to X_3 .

38. The system of claim 36 wherein the wafer stage is positioned relative to the projection lens assembly according to the following relationship:

$$U_R = X_7 - X_6 - (e/d)(X_6 - X_5)$$

wherein,

U_R corresponds to displacement of the reticle stage relative to the projection lens assembly along an axis parallel to the measurement beams,

5 X_7 corresponds to the optical path length change measured by the beam directed at the reticle stage which is the adjacent distance from the beam directed at the projection lens assembly,

X_8 corresponds to the optical path length change measured by the beam directed at the reticle stage which is the spacing distance from the beam corresponding to X_7 ,

10 X_6 corresponds to the optical path length change measured by the beam directed at the projection lens assembly that is the adjacent distance from the beam corresponding to X_7 ,

X_5 corresponds to the optical path length change measured by the beam directed at the projection lens assembly that is the spacing distance from the beam corresponding to X_6 .

15 39. The system of claim 36 wherein the wafer stage is positioned relative to the projection lens assembly according to the following relationship:

$$\Theta_w = (X_2 - X_1)/d - (X_4 - X_3)/d$$

wherein,

20 Θ_w corresponds to rotation the wafer stage relative to the projection lens assembly along an axis perpendicular to the reference plane,

X_2 corresponds to the optical path length change measured by the beam directed at the wafer stage which is the adjacent distance from the beam directed at the projection lens assembly,

25 X_1 corresponds to the optical path length change measured by the beam directed at the wafer stage which is the spacing distance from the beam corresponding to X_2 ,

X_3 corresponds to the optical path length change measured by the beam directed at the projection lens assembly that is the adjacent distance from the beam corresponding to X_2 , and

30 X_4 corresponds to the optical path length change measured by the beam directed at the projection lens assembly that is the spacing distance from the beam corresponding to X_3 .

40. The system of claim 36 wherein the wafer stage is positioned relative to the projection lens assembly according to the following relationship:

$$\Theta_R = (X_8 - X_7)/d - (X_6 - X_5)/d$$

35 wherein,

Θ_R corresponds to rotation the reticle stage relative to the projection lens assembly along an axis perpendicular to the reference plane,

X_7 corresponds to the optical path length change measured by the beam directed at the reticle stage which is the adjacent distance from the beam directed at the projection lens assembly,

X_8 corresponds to the optical path length change measured by the beam directed at the reticle stage which is the spacing distance from the beam corresponding to X_7 ,

X_6 corresponds to the optical path length change measured by the beam directed at the projection lens assembly that is the adjacent distance from the beam corresponding to X_7 ,

X_5 corresponds to the optical path length change measured by the beam directed at the projection lens assembly that is the spacing distance from the beam corresponding to X_6 .

41. An exposure system comprising:

a wafer stage;

a reticle stage;

a projection lens; and

an interferometer system comprising interferometer optical components

configured to determine said wafer stage and said reticle stage positions with respect to said projection lens while accounting for rotational movement of the interferometer

optical components.

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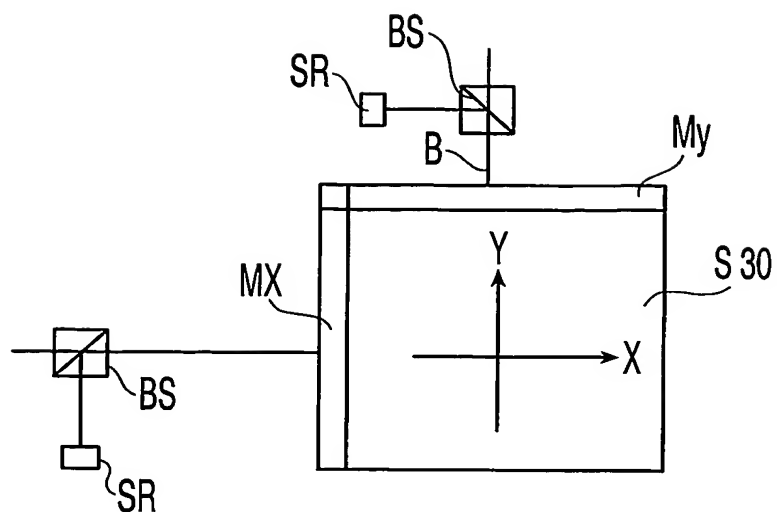


Fig. 1
Prior Art

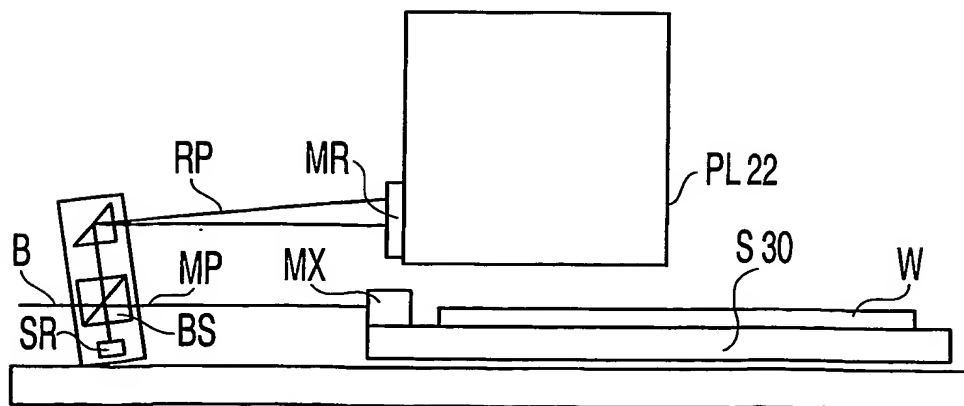


Fig. 2
Prior Art

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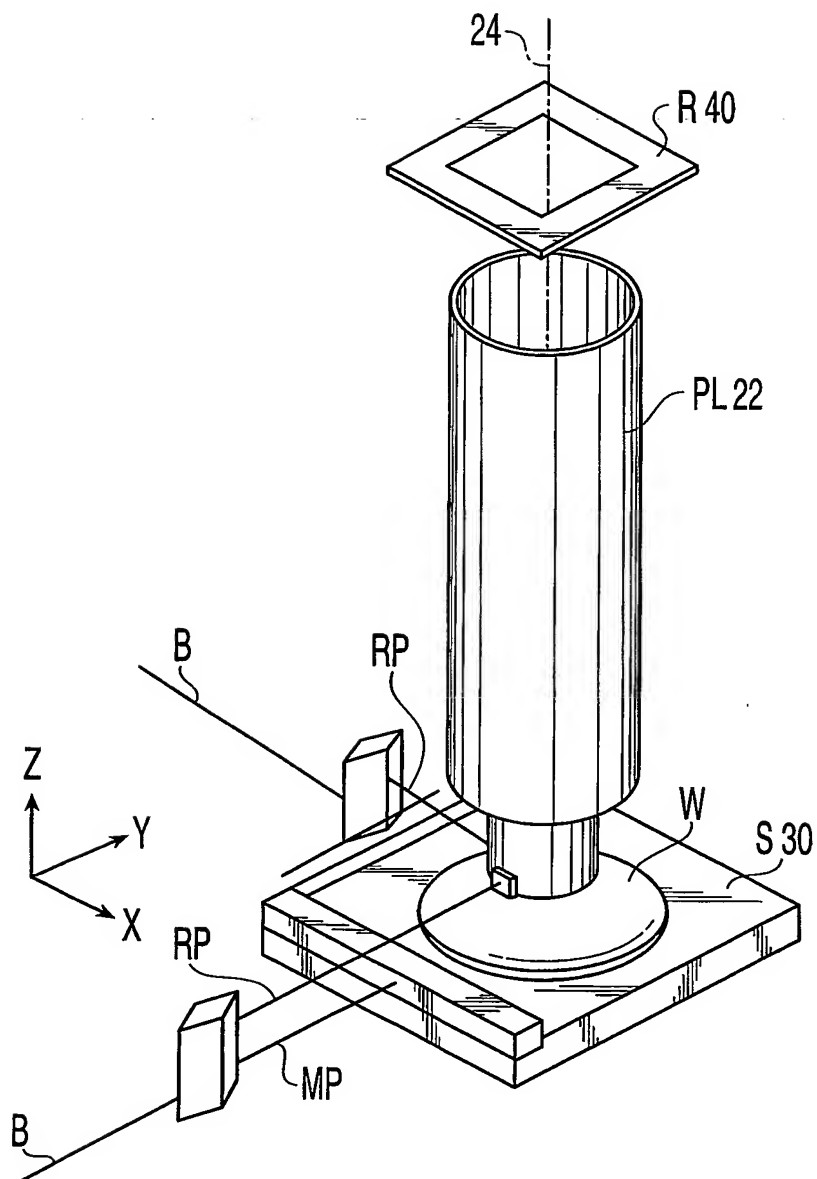


Fig. 3
Prior Art

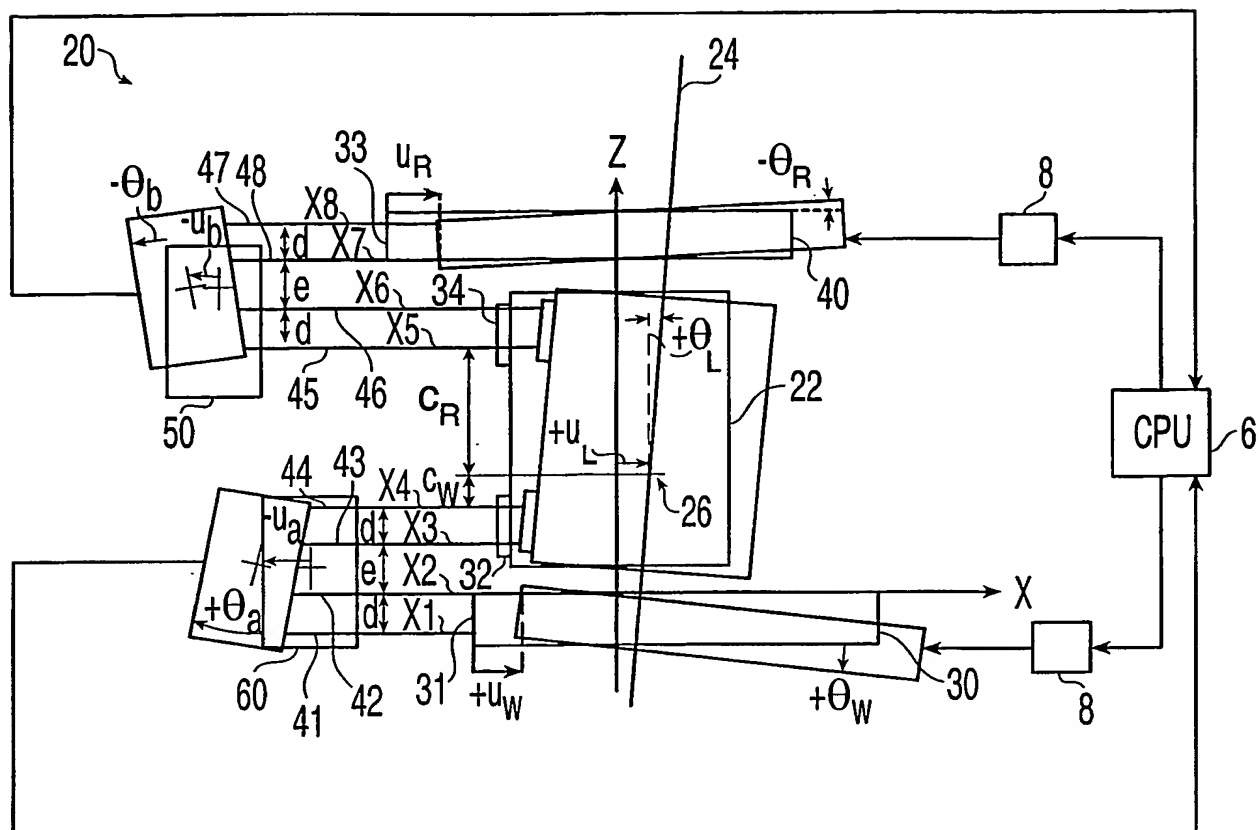


Fig. 4

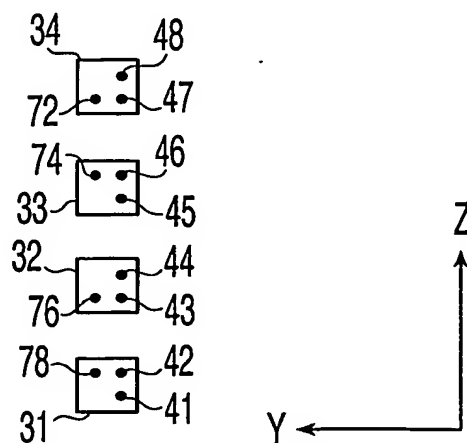


Fig. 5

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/US02/25238

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) : G03B 27/42, 27/52, 27/54, 27/32; G03F 9/00, 5/00; G01B 11/02, 11/00
US CL : 355/53, 55,67,77; 430/5,22,311,312; 356/356, 357, 363

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
U.S. : 355/53, 55,67,77; 430/5,22,311,312; 356/356, 357, 363

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
USPAT

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6313918 B1 (HILL et al) 06 November 2001 (06.11.2001), columns 3-4, 70, 74, 75, Col 50	1-41
A	US 5365342 A (AYATA et al) 15 November 1994 (15.11.1994)	1-41
A	US 5991034 A (OHTSUKA) 23 November 1999 (23.11.1999)	1-41

☐ Further documents are listed in the continuation of Box C.

☐ See patent family annex.

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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"O" document referring to an oral disclosure, use, exhibition or other means	"&" document member of the same patent family
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search

21 October 2002 (21.10.2002)

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